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Energetic Particles from Laser Produced Plasmas and Applications

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In Collaboration with…

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- 2) Centro Ricerche ENEA, Frascati, Italy
- 3) Università di Roma “La Sapienza”
- 4) Università del Salento and INFN, Lecce, Italy
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- 6) Università di Messina and INFN, Italy

SUMMARY

- **NANOSECOND vs FEMTOSECOND LASER-MATTER INTERACTION AT HIGH INTENSITIES**

- **ENEA EXPERIMENT: THE ROLE OF PARAMETRIC INSTABILITIES**

- **PALS EXPERIMENT: THE ROLE OF THE NANOPARTICLES AND RESONANT ABSORPTION**

- **CONCLUSIONS AND PERSPECTIVES**

Supra-thermal particles in Laser-Matter Interaction at High Intensities

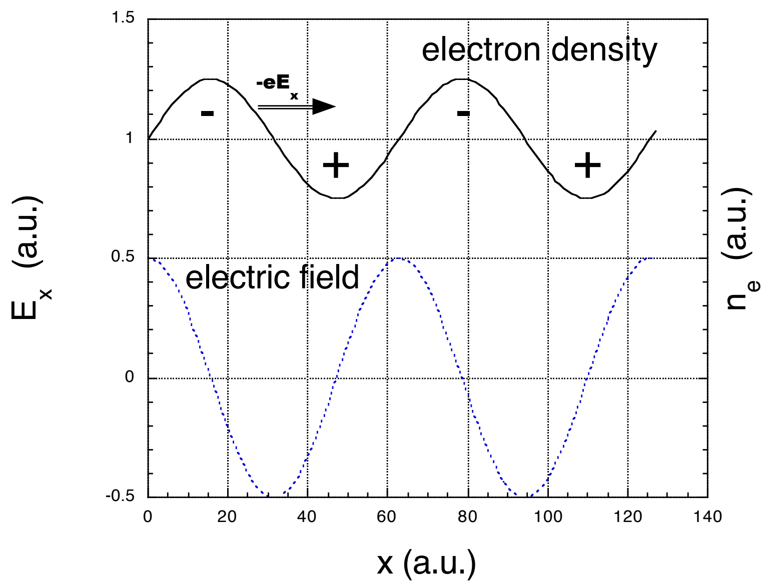
The laser-matter interaction at high intensity is accompanied by the production of particles with a kinetic energy much higher than that would compete at the plasma produced temperature.

Supra-thermal particle populations and Electron Plasma Waves

The origin of this supra-thermal electronic and ion population component is mainly due to the presence of electronic plasma waves, responsible of the acceleration of a small electron fraction and, as a consequence of the escape of these electrons from the irradiated target, of a few ions.

Electron Plasma Waves (1)

The mechanisms of creation of the electron plasma waves are manifold. They depend heavily on the intensity and duration of the laser pulse.

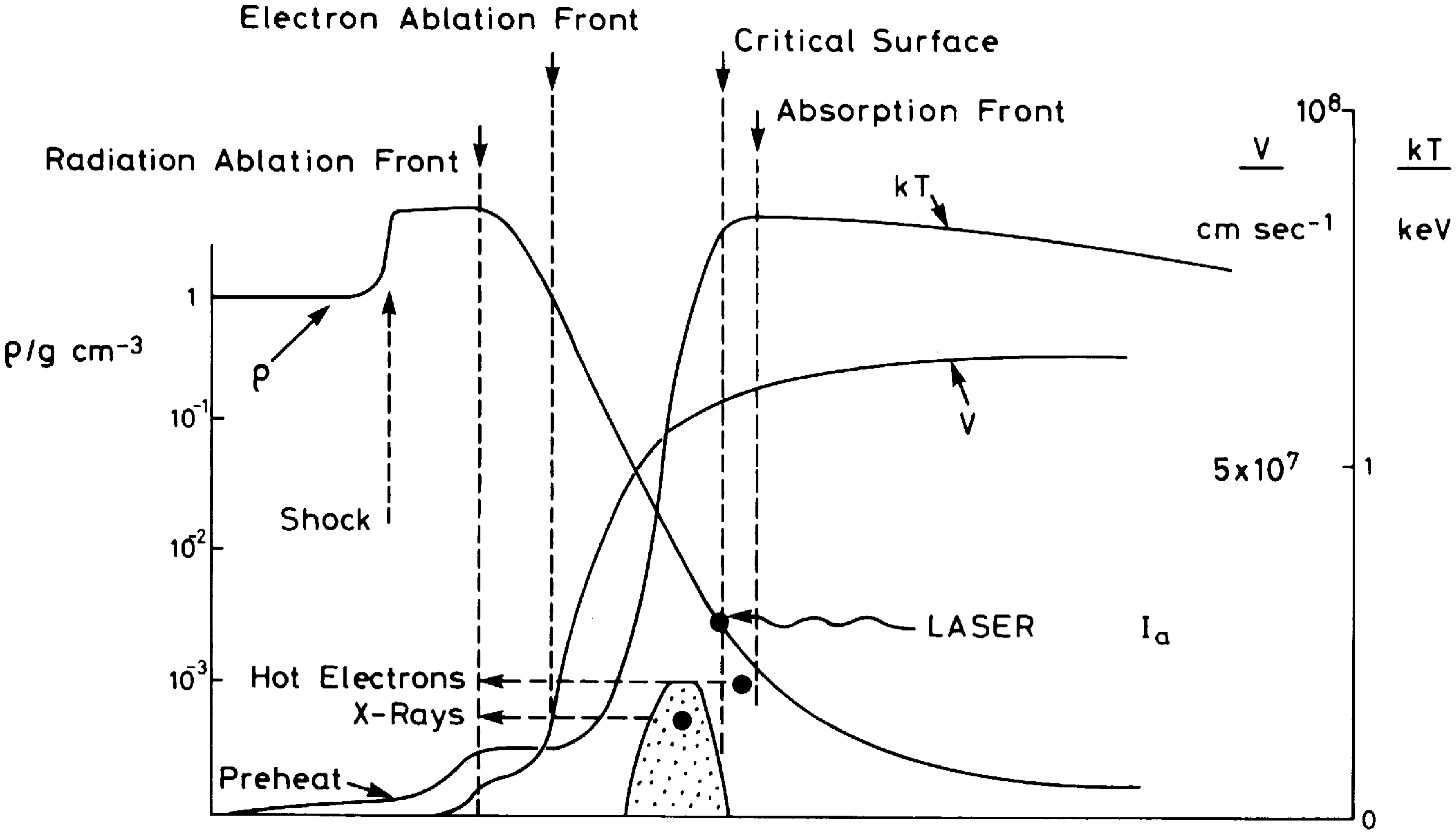


Electron Plasma Waves (2)

- For **pulses of nanosecond** duration the electron waves are created mainly by the onset of some **parametric instabilities** (SRS, TPD) and specific absorption mechanisms (Resonant Absorption).
- In the regime of **ultra-short pulses (femtoseconds)** these instabilities not have enough time to grow and the electron waves are excited by almost resonant mechanisms induced by **ponderomotive forces** (SMLWF, LWF, Bubble regime). However, in this regime energetic particles can be produced also by **other mechanisms**, such as the Coulomb explosion or the RPA.

D. Giulietti, Propagation of super-intense and ultra-short laser pulses in plasmas, Physics Procedia, 62, 48-58, 2015, doi: 10.1016/j.phpro.2015.02.010

Nanosecond laser pulse on solid target @ 10^{14} W/cm^2



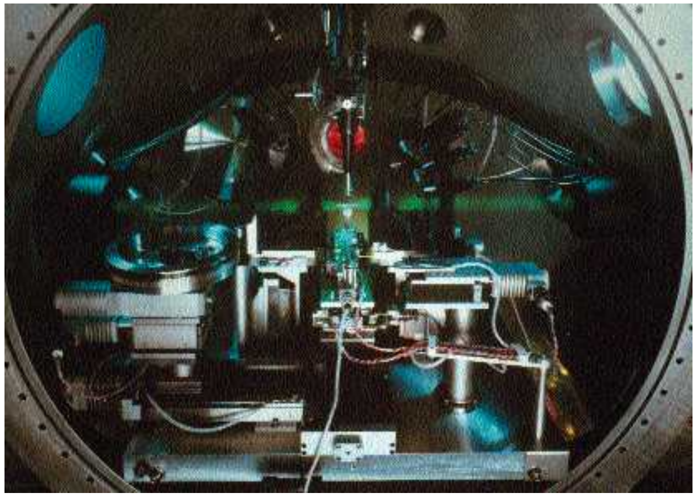
Courtesy of M.H. Key

ENEA experiment

Fast particles and parametric instabilities

2015

ABC LASER: 2 BEAMS, 100J in 2ns



Study of p-^{11}B fusion reaction

Relevance of p-^{11}B fusion reaction

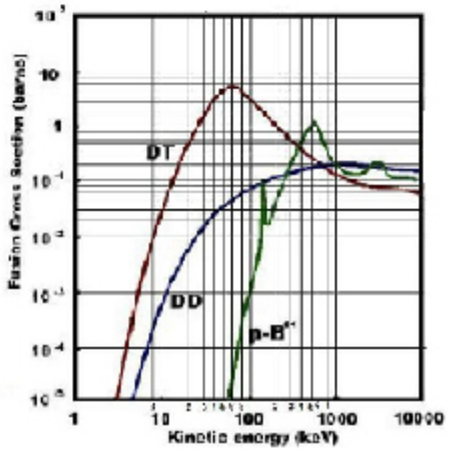
- Fusion Energy (clean, high T)
- Nuclear Astrophysics (p-p chain)

Determination of fusion cross-sections at low energies

- Beam-target experiments (*electron screening*)
- Plasmas (*few reactions at low T*)

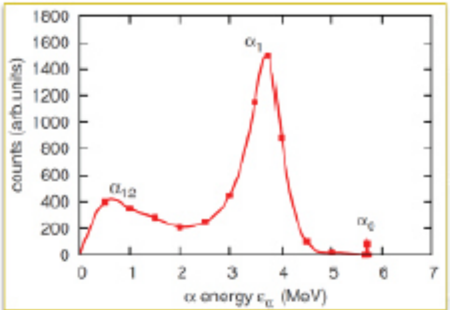
Experiments

- p+^{11}B fusion reactions observed in laser produced plasmas in the ps laser timescale, at intensities I ≈ 10^{18} W/cm^2 [1-4].
- Experiments with the 2-beam laser ABC at lower intensities (I ≈ 10^{14} W/cm^2, 3 ns pulse duration) have given evidence of α particles production [5]



$$^{11}B + p \rightarrow \alpha_0 + {}^8Be$$
$$^{11}B + p \rightarrow \alpha_1 + {}^8Be^*$$
$$^8Be^* \rightarrow 2\alpha_{12}$$

$$\alpha_0 \rightarrow 5.7\,MeV$$
$$\alpha_1 \rightarrow 3.8\,MeV$$
$$\alpha_{12} \rightarrow (0-5)\,MeV$$



[1] D.C. Moreau, Nucl. Fusion 17, 1, 13 (1977)
[2] V. P. Krainov, Laser Phys. Lett. 2, 89 (2005).
[3] V. S. Belyaev *et al*, Phys. Rev. E 72, 026406 (2005).
[4] S. Kimura *et al*, Phys. Rev. E 79, 038401 (2009).
[5] A. Bonasera *et al*, Proc. Int. Conf. Fission and Prop. Neut. Rich Nuclei, 2007, Sanibel Island, USA.

Coutesy of R. De Angelis

Shot parameters

We refer to these laser-target parameters:

· Target : Natural B, 400 nm thickness

· Two beams, maximum focus ($40\mu m$ diameter)

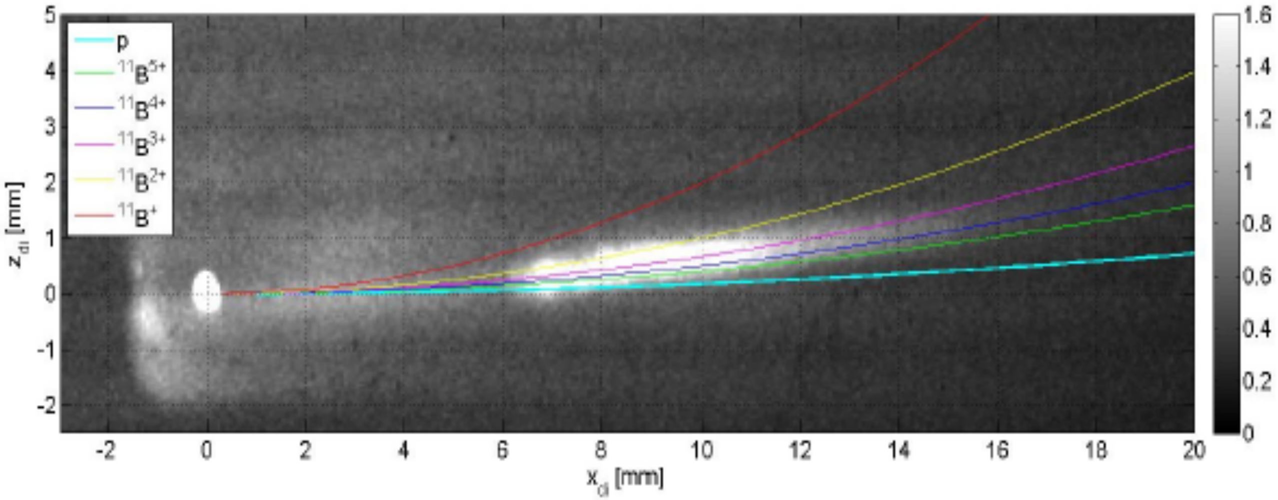
· Beam A intensity: $1.3 \times 10^{15} W/cm^2$

· Beam B intensity: $1.2 \times 10^{15} W/cm^2$

Particle detection : Thomson parabola + Imaging Plates

- B = 0.21 T
- ΔV = 100 V
- Deflecting distance: 16 mm; Drift distance: 120 mm
- Pinhole diameter: 200μm
- Detector: Imaging Plates
- IP scanner: Durr NDT CR35 Bio

Best fit for $^{11}B^{3+}$

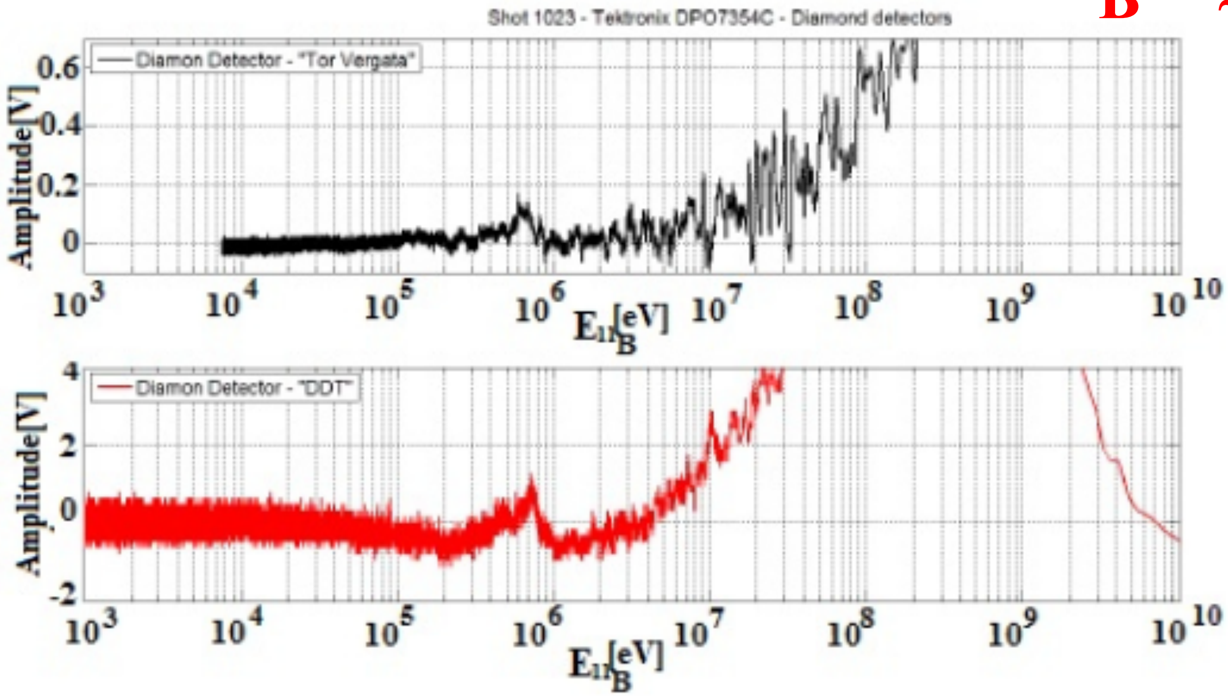


Particle detection : Diamond detectors

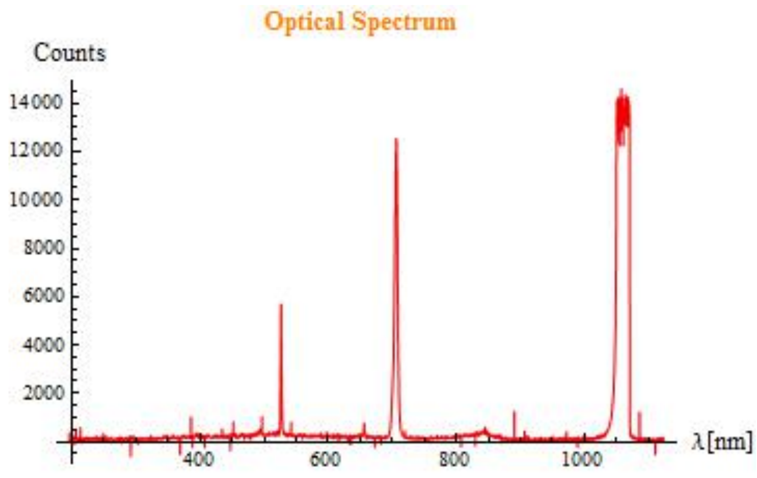
TOF

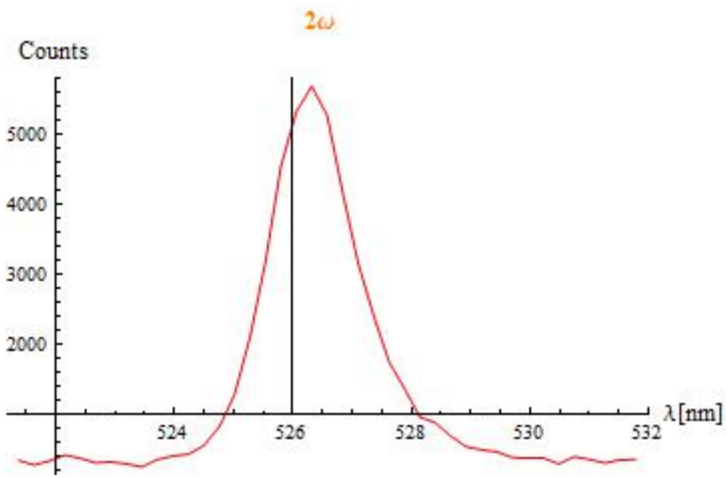
- Active area: 2 mm × 2 mm, separation between the electrodes: $d_{drift} = 20\ \mu$ m average
- $\Delta V = 40$ V, related electric field = 2 MV/m → saturation of the carrier drift velocity
- Saturated carrier drift velocity : $v_d = (5\text{-}10)10^4$ m/s
- Energy necessary for the production of an electron-hole couple = 13 eV

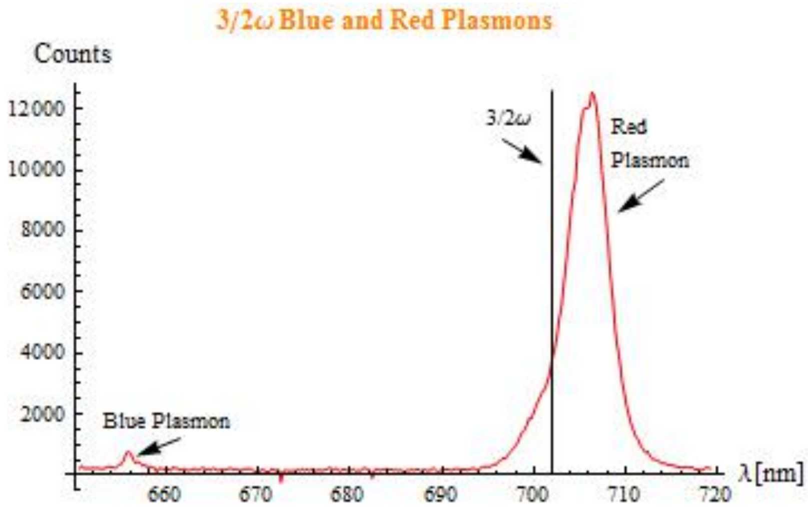
$^{11}B^{3+} \approx 700$ keV



Parametric Instabilities





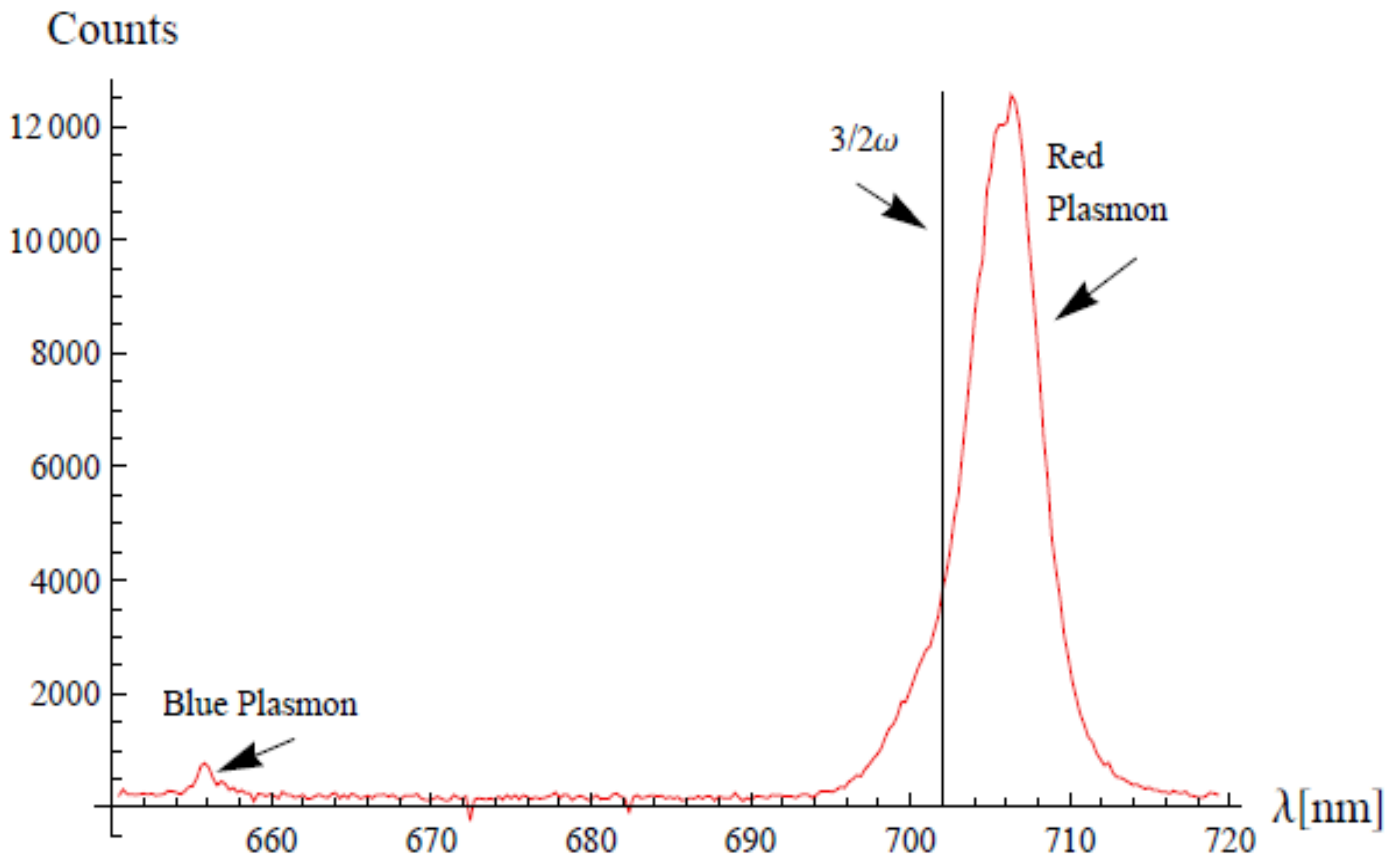


Supra-thermal electrons ≈ tens of keV

Spectral measurements: TPD

The spectral analysis of the radiation emitted by the plasma in the visible range is performed by means of a grating spectrometer (Ocean Optics $HR4000CG-UV-NIR$), coupled with cooled CCD.

$3/2\omega$ Blue and Red Plasmons



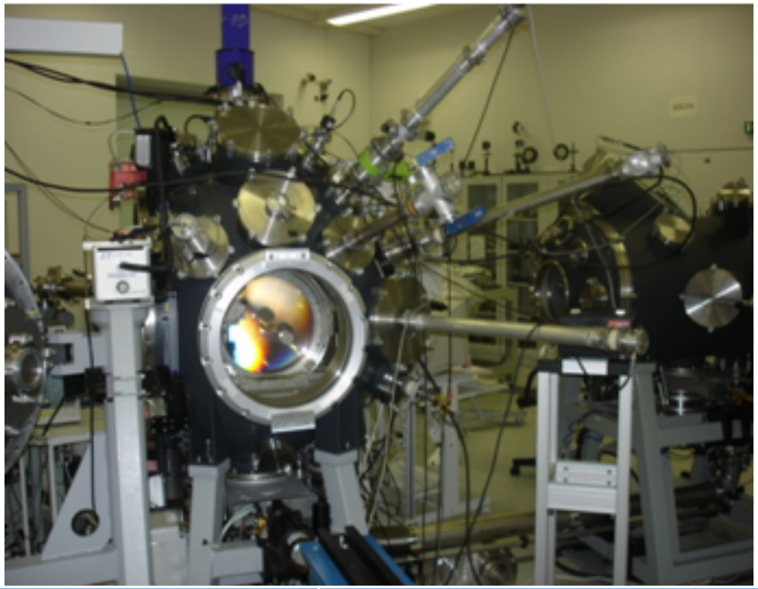
The measured temperature at $n_c/4$ surface is around $11.5keV$

PALS EXPERIMENT

2014

THE ROLE OF THE NANOPARTICLES AND RESONANT ABSORPTION

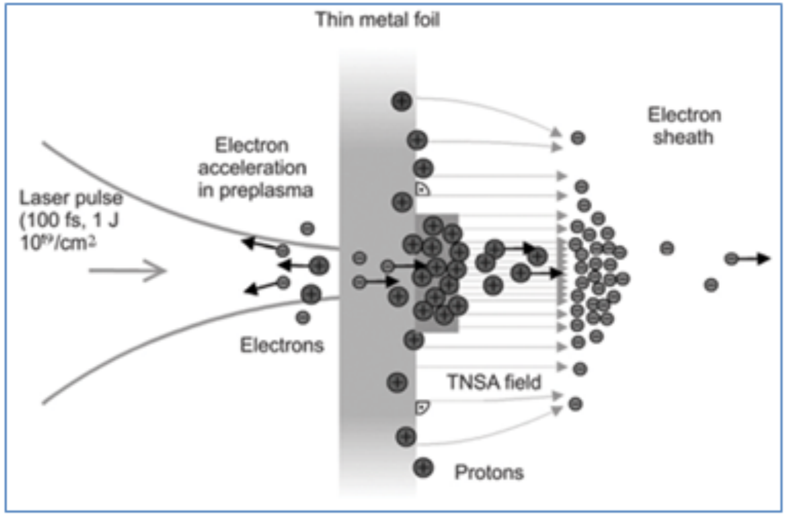
ASTERIX



Properties	Laser Asterix
Intensity	$10^{15\text{-}16}$ W/cm^2
Maximum Energy	1 kJ
Pulse duration	300 ps
Wavelenght	1315 nm – 438 nm

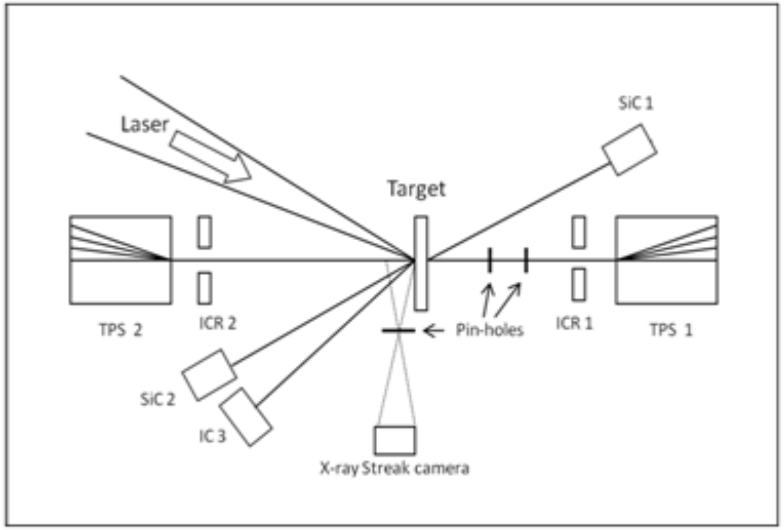
Focal dimension	70 μm
Beam profile	Gaussian
Beam diameter	29 cm
Power	3 TW
Repetition rate	1 shot/20 min

Experimental set-up



TNSA Regime

Advanced thin targets (1-10 μm thick)

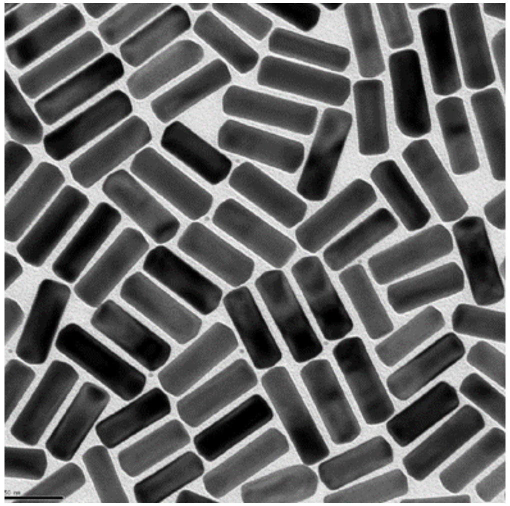


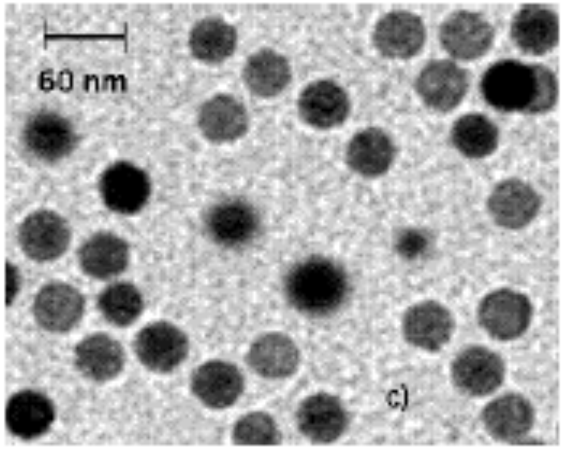
Diagnostics

- SiC in TOF configuration
- Ion collectors (IC) in TOF configuration
- Thomson parabola specrometer (TPS)
- X-ray streak camera

Au Nanorods and Nanospheres

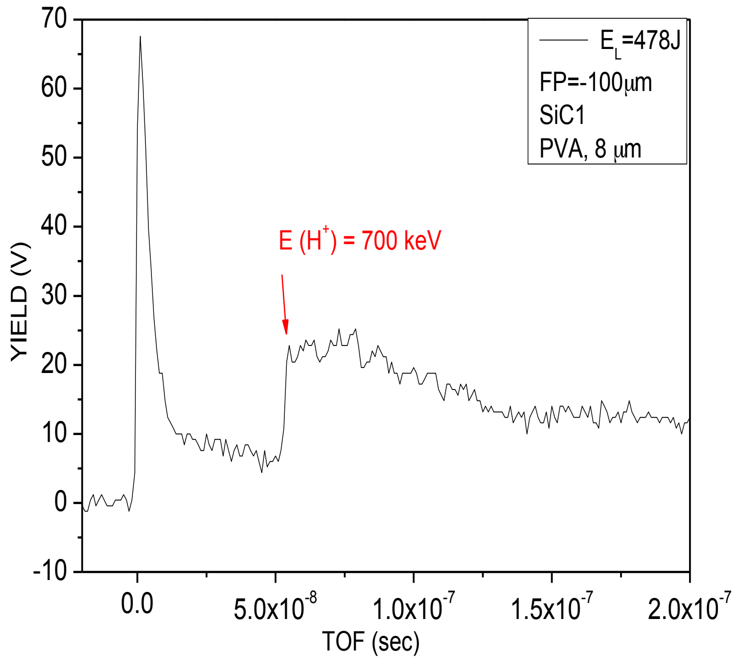
The resonant frequency for these oscillations in metallic NPs corresponds typically to UV–Vis-IR light and consequently, the Surface Plasmons resonance arise absorption bands in this region of the spectrum.



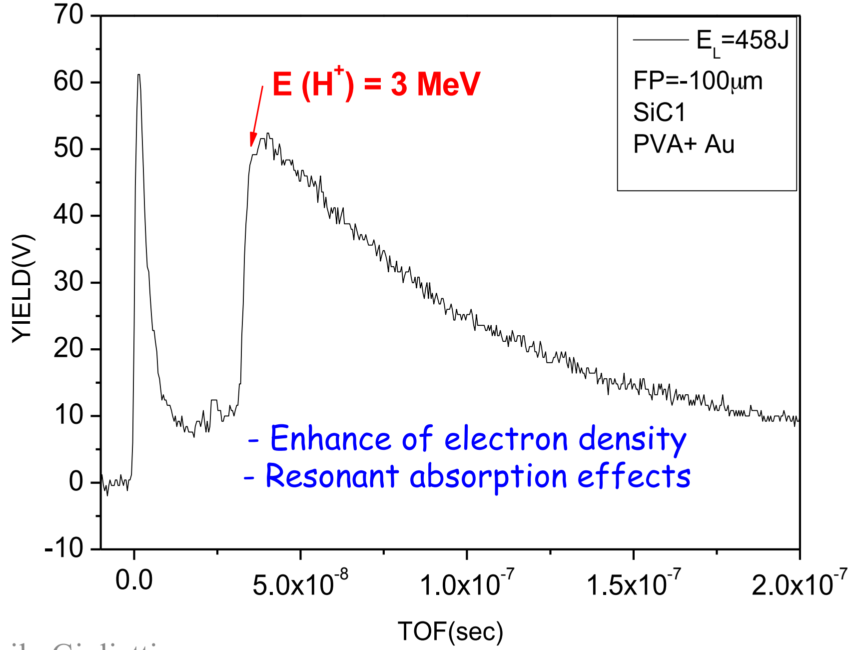


TOF Spectra from SiC detectors

D_{TOF} = 62 cm



Pure PVA
polyvinyl alcohol, $(C_2H_4O)_x$



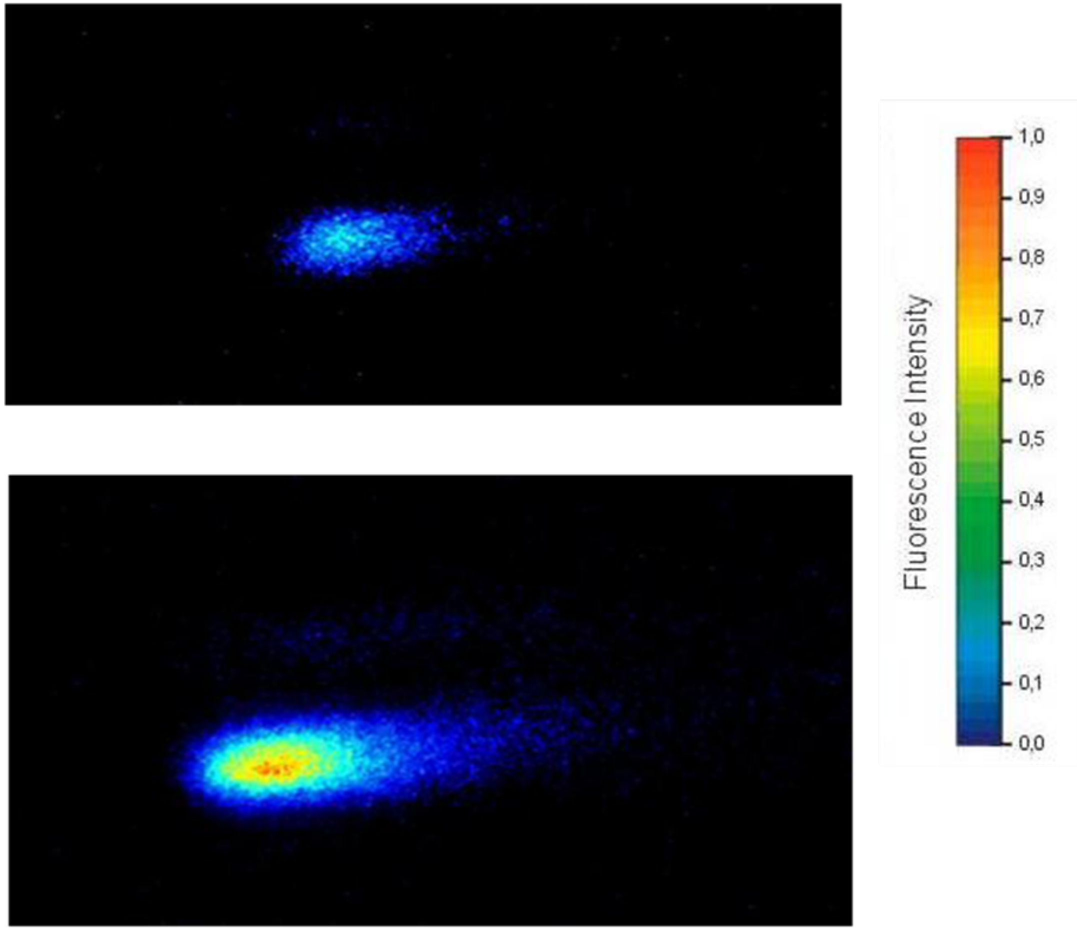
Au nanospheres, D ~ 50 nm,
Embedded in PVA+A.R. by Spinning deposition (10 mg/10 ml), 10 um thick

X-Rays Streak Camera

PVA

kT~ 0.5 keV

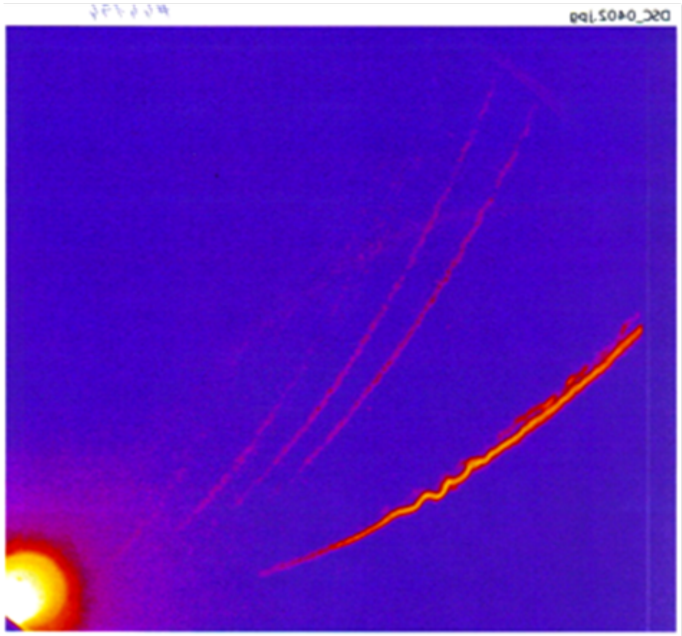
kT~ 2.5 keV

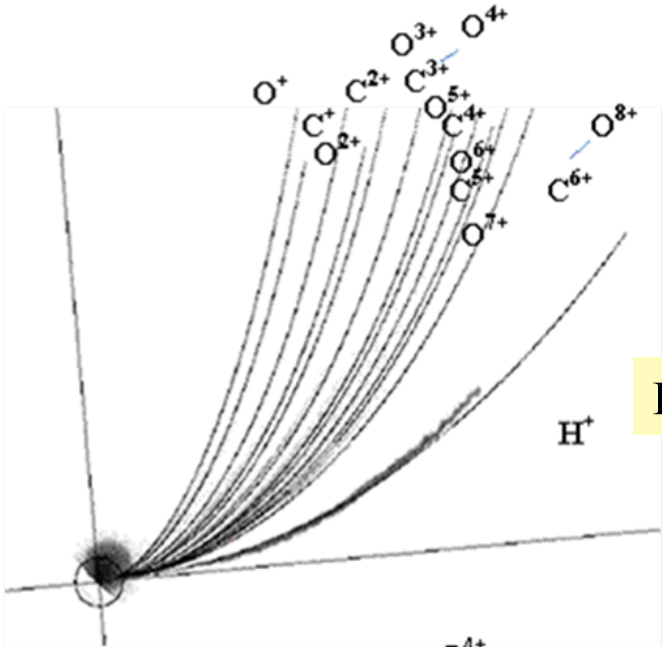


PVA+AuNPs

Thomson Parabola Analysis

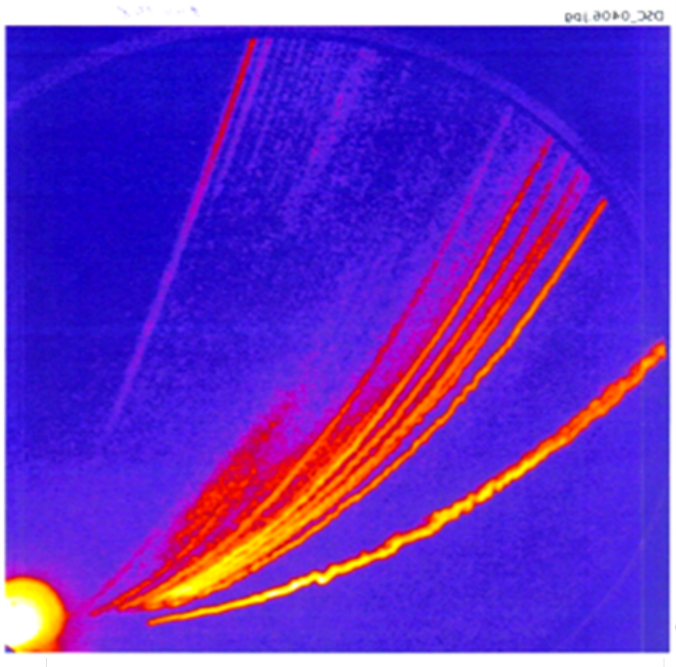
TPS

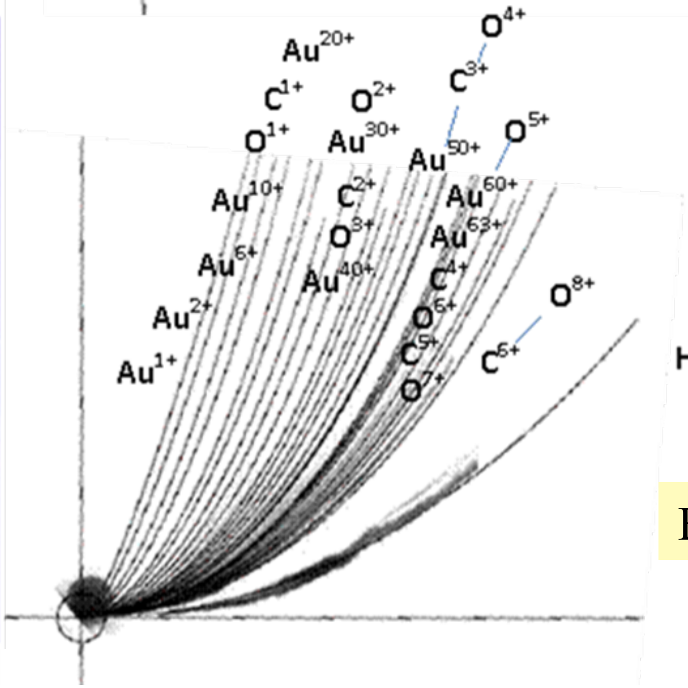




PVA

$E_{p\text{-max}} \sim 650$ keV

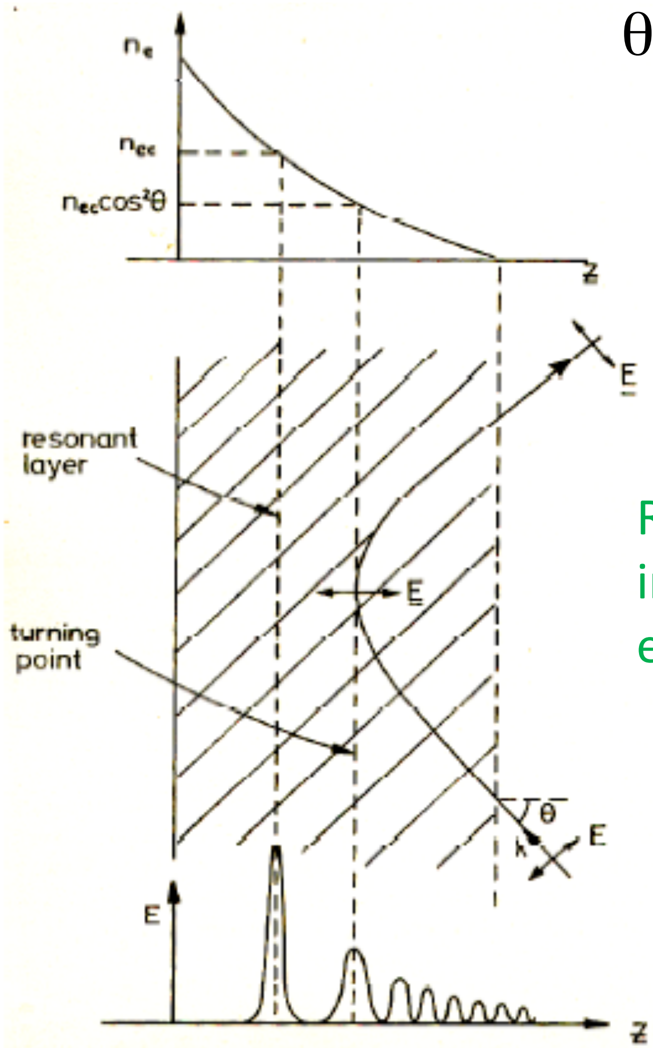




PVA + Au NP

$E_{p\text{-max}} \sim 1.9$ MeV

RESONANT ABSORPTION



$$\theta_{inc} = 0° \longrightarrow \vec{E}\cdot\vec{\nabla}n_e = 0$$

No resonant absorption

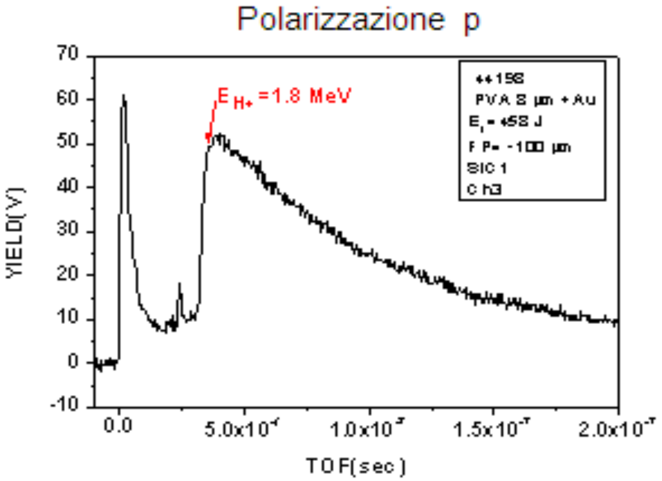
$$\theta_{inc} \neq 0 \rightarrow \vec{E}\cdot\vec{\nabla}n_e \neq 0$$

Resonant absorption occurs for linear polarization in p incidence: resonant longitudinal plasma wave excitations at ≈ critical density surface.

Resonant absorption of about 50% laser energy for

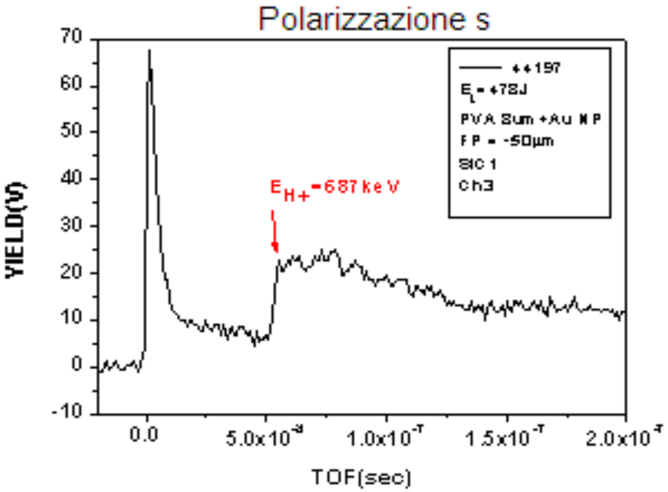
$$\vartheta_{max} \approx \arcsin\left[0.8\left(\frac{c}{\omega_L L_n}\right)^{\frac{1}{3}}\right]$$

TOF



E_p = 1.8 MeV

p-polarized light
Θ=30°
FP = -100 um
E= 480 J



E_p = 0.7 MeV

s-polarized light
Θ=30°
FP = -100 um
E= 480 J

L. Torrisi, L. Calcagno, D. Giulietti, M. Cutroneo, M. Zimbone, J. Skala, Laser irradiations of advanced targets promoting absorptio resonance for ion acceleration in TNSA regime,NIMB, 2015 (in press) http://dx.doi.org/10.1016/j.nimb.2015.01.019

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CONCLUSIONS AND PERSPECTIVES

Istituto Nazionale di Fisica Nucleare

* Since the beginning of the high power pulsed laser era, the energy of some particles, emerging from plasmas generated in laser matter-interaction, was found sensibly higher than that expected on the basis of the plasma estimated temperature.

* The evolution in the laser pulse amplification techniques and the progressive shortening of the pulse duration was accompanied by a corresponding increase in power. This led to the production of particles of increasingly greater energy as new acceleration mechanisms could be reached.

* The characteristics of these sources of energetic particles strongly depend on the laser-pulse and target parameters, opening to different applications, from **advanced acceleration technique** to **medicine**, from **new X-ray sources** to the **inertial confinement fusion**.

* **Ultra-short and ultra-intense laser pulses are accompanied by ps-ns pedestal that can induce physical mechanisms interfering with the ones used to efficiently accelerate the particles, if the (main pulse/pedestal) contrast ratio is not low enough.**

D. Giulietti and A. Curcio, Laser induced plasma channels and related X-gamma ray sources, NIMB, 2015 (in press) http://dx.doi.org/10.1016/j.nimb.2015.02.011
D Giulietti, The particle laser-plasma acceleration in Italy. JOURNAL OF PHYSICS. CONFERENCE SERIES, vol. 508 , 2014
M. Ferrario et al., Interdisciplinary research infrastructure based on dual electron linacs and lasers. NIM A, vol. 740, p. 138-146, 2014.

PPLA is a biennial opportunity of meeting between experts of laser-matter interaction at high intensity and the related generation of particle and radiation of high energy. It will be organized by ENEA, Fusion Department, and it will be held in Frascati, 20 km from Rome, Italy.
The topics include also investigations performed with ultra short lasers and laser applications in different fields.
The organizing committee hopes numerous participation.
See You in Frascati

Organizing Committee

R. De Angelis, ENEA - Frascati , IT- D. Giulietti, University of Pisa, IT -
V. Nassisi, University of Salento,IT -L. Torrisi, University of Messina,IT

Topics

Laser-Matter interaction
Laser ion-sources
Laser particle acceleration
Physics of non-equilibrium plasmas
Theoretical models of laser plasmas
Photon and particle emission from pulsed plasmas
Ultra short lasers
Pulsed Laser Deposition
Applications of laser beams and pulsed plasmas
Laser plasma diagnostics
Advanced targets
Laser plasmas for material analysis
Laboratory and nuclear astrophysics
Laser induced fusion
Laser plasma innovative X-ray sources

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M. Ferrario -	INFN, IT
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V. Nassisi -	UniSalento, IT
L. Torrisi -	UniME, IT
J. Badziak -	IPPLM, PL
D. Batani -	CELIA, FR

Proceedings will be published in Journal of Physics: Conference Series , IOP

The best paper by a young researcher will be awarded the Laszka prize

Abstract deadline: 15 June 2015

Info: www.ppla2015.enea.it
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Local Organizing Committee

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